Actinic detection of defects in Extreme Ultraviolet Lithography Mask Blank

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INTRODUCTION

Optical projection lithography has been the workhorse of the semiconductor industry for making integrated circuits for the past three decades. However, it is widely believed that optical lithography will finally run out of steam for circuit fabrication with <0.1 μm critical dimensions and that a new lithographic approach is needed to sustain the further scaling of integrated circuits[1]. Extreme ultraviolet Lithography (EUVL) is one of the leading candidates to follow optical lithography in the next century[2]. Utilizing 11-14 nm radiation with an all-reflective projection optical system, EUVL is expected to provide resolution down to 30 nm with reasonable depth of focus and adequate wafer throughput[3].

The mask architecture that is being actively pursued for EUVL is a reflective mask, consisting of absorber patterns on top of multilayer reflective coatings on a robust substrate[4]. Since a defect on the mask will disrupt the image of the circuit pattern on the wafer, the capability to produce defect free masks is crucial in any advanced lithographic technology. A recent simulation study suggests that a defect as small as 80 nm on the EUVL mask is "printable"[5]. This tight defect specification necessitates a very stringent control on the level of defects in mask making: the mask blank needs to be free of any printable defect and the absorber circuit pattern also needs to be free of any printable defect. While repair technologies are being actively studied for defects in the absorber pattern[6], defects in the mask blank are essentially impossible to repair. Therefore, producing low defect density EUVL mask blanks and inspecting them represents a very important technical challenge to meet for the commercial viability of EUVL technology.

While there are several inspection strategies for EUVL mask blanks such as visible light scattering and scanning electron microscopy, these probes tend to have a limited probing depth into the multilayer coating. Furthermore, the connection between the visible light scattering cross section and the EUV response is not well understood. Therefore, to capture all the printable defects in the EUVL multilayer mask blank, an inspection method at the operating wavelength (at-wavelength inspection) is necessary, at least at the developmental stage of the technology. Only an at-wavelength inspection technique can provide reliable feedback to the low defect density multilayer deposition technique and can qualify other inspection techniques for commercial EUVL system.

DEVELOPMENT OF EUV SCANNER FOR AT-WAVELENGTH MASK INSPECTION

As a proof-of-principle at-wavelength inspection system for EUVL mask blanks, we have built an EUV scanner based on raster scanning a focused EUV beam along the Mo/Si multilayer coated mask blank.[7] As shown in Figure 1, when the focused EUV beam is incident on a defect, the amplitude and phase of the reflected radiation is perturbed by the defect. This perturbation manifests itself as an intensity reduction in the speculary reflected beam (bright field) and scattering of photons into non-specular directions(dark field). The scattered radiation

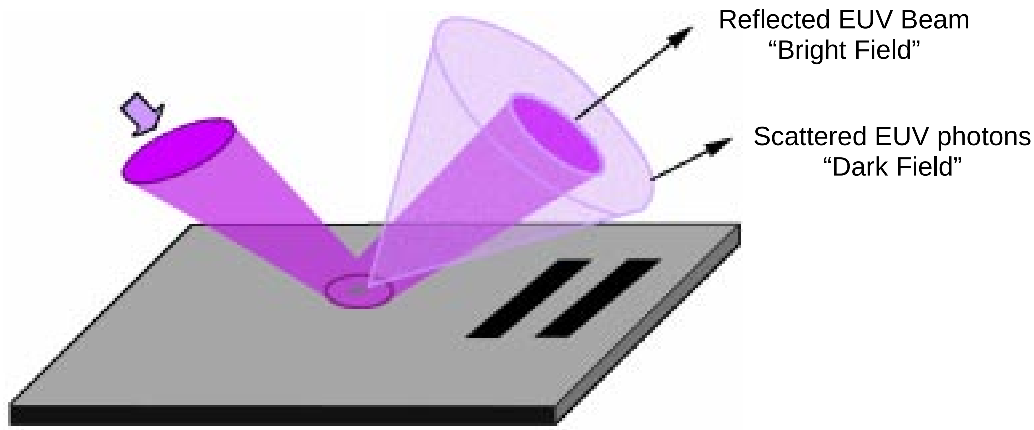

Figure 1. Concept behind the current actinic scanner is shown. When the focused radiation is incident on a defect, intensity of the speculary reflected beam is reduced (bright field) and photons are scattered into a non-specular direction (dark field).

is captured by microchannel plate detector. The microchannel plate has an opening at the center so that the specularly reflected beam passes through the opening and can be captured by a bright field detector situated behind the microchannel plate. The focusing of the incoming EUV radiation is achieved by a pair of glancing angle bendable mirrors in the Kirkpatrick-Baez configuration.

The system is installed at BL 11.3.2 at the ALS, which is the dedicated beamline for EUVL mask blank defect inspection. Thusfar, we have concentrated on studying properties of various programmed defects on an EUVL mask blank. Specifically, we studied defects beneath the multilayer (substrate defects or "phase" defects) or defects on top of the multilayer ("opaque" defects). Figure 2 and Figure 3 shows the bright field and dark field inspection results from an array of phase programmed defects (Figure 2) and opaque programmed defects (Figure 3). The phase programmed defects were made by fabricating a small bump on the silicon substrate before the multilayer deposition. When the multilayer is deposited, the multilayer deposition over the bump is conformal, resulting in a coherent bump in the multilayer. This will produce a localized phase shift in the reflected wavefront. The opaque programmed defects were made by depositing and patterning a small absorber island (in this case aluminum). Because the absorption is very strong in the EUV spectral region, any particle on top of the multilayer coating will significantly reduce the intensity of the reflected beam.

As shown in Figure 2, detection of scattered photons in the dark field shows a superior sensitivity to phase defects. Strikingly, the dark field signal is quite weak for opaque defects as shown in Figure 3. Correlating the signal strength between the bright field and the dark field can provide a clue to whether a defect is a phase (substrate) defect or an opaque defect.

In a recent experiment with programmed defects, we also demonstrated that we can detect a defect as small as 100 nm in lateral dimension. The sensitivity of our system depends critically on the spot size we can achieve. The best spot size achieved so far is 10 μm^2 in area, which results in approximately 0.1% change in the bright field for a 100 nm diameter opaque defect.

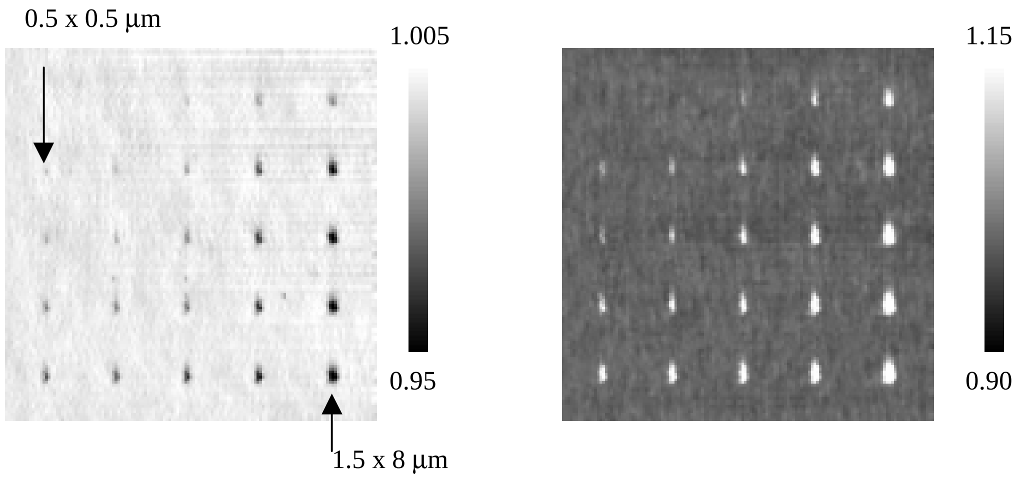

Figure 2. (a) The bright field scan of the 25 nm high programmed defect sample. The size of the programmed defect ranges from 1.5 by 8 µm to 0.5 by 0.5 µm as indicated in the figure. (b) The dark field scan of the same region as 3(a) Note the phase defects appear very distinctively in the dark field

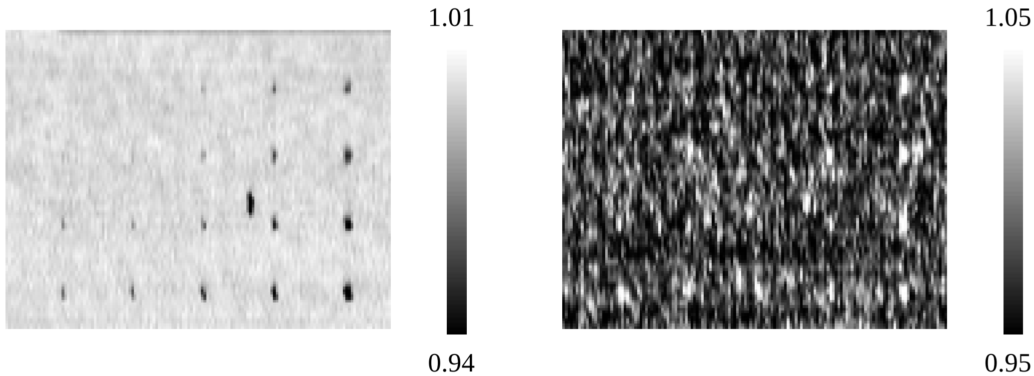

Figure 3. (a) The bright scan of the opaque programmed defect sample. The sample was fabricated by depositing and patterning absorber material such as aluminum to simulate particles on top of the multilayer coating. The size of the defects are similar to that shown in Figure 2.
(b) The dark field scan of the same region as 5(a). The visibility of defects are low compared to that of phase defects even though the scale has been adjusted.

FUTURE EXPERIMENTS

Based on the system learning that we acquired during 1998, we are planning to do a series of experiments. Specifically, experiments for cross correlating results obtained with a visible light scattering defect inspection tool and our EUV scanner will be performed. It is anticipated that this kind of correlation study will reveal the EUV response of various defects found on the EUVL mask blank and also test the sensitivity of the visible light scattering inspection system to EUV specific defects. Another crucial experiment that is being planned is a defect counting experiment. A relatively larger area of an EUVL mask blank will be scanned and the statistics of defects found on the mask blank will be compiled.

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